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TO: Joyce C. Butler,
Chief, Dockets Branch

FROM: Julius Knapp
Branch Chief,
Frequency Allocations Branch
Spectrum Engineering Div., OET

SUBJECT: Interim Report: Estimate of Availability of Spectrum for Advanced Television (ATV) in the Existing Terrestrial Broadcast Bands and Analysis of UHF TV Receiver Interference Immunities Considering Advanced Television

DATE: September 6, 1988

The Commission adopted a Tentative Decision and Further Notice of Inquiry in the subject proceeding on September 1, 1988. Pursuant to the Commission's decision we hereby request that the two attached technical memos be placed in the official record for MM Docket No. 87-268. An initial number of copies were made available to ~~the public through~~ the press office on September 1. The Commission item requests comments on the technical memos.

Julius B. Knapp
Julius Knapp

87-268

Federal Communications Commission
Office of Engineering and Technology
Spectrum Engineering Division

INTERIM REPORT:
ESTIMATE OF AVAILABILITY OF SPECTRUM FOR ADVANCED TELEVISION (ATV) IN THE EXISTING TERRESTRIAL BROADCAST BANDS

OET Technical Memorandum
FCC/OET TM88-1
August 1988

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EXECUTIVE SUMMARY

The Office of Engineering and Technology (OET) is studying the availability of spectrum for advanced television (ATV) systems. All of the proposed ATV systems now under consideration require either no additional spectrum, 3 additional MHz, or 6 additional MHz. The OET study investigates the availability of spectrum in blocks of 3 or 6 MHz within the bands currently allocated for terrestrial broadcast of television.

The study examines possibilities for providing additional spectrum adjacent to each channel presently assigned and also the larger class of possibilities in which the additional block of spectrum may be located elsewhere in one or another of the bands allocated to TV broadcasting. A later phase will investigate the question of whether substantial improvements in spectrum availability could be obtained through a limited amount of repacking of the TV allotments.

Table 1 summarizes results so far. Two distances (160 and 300 km) are tried as minimum separations and give what we believe are reasonable upper and lower bounds on the percentage of stations that can be assigned additional spectrum. The 160-km separation distance (100 miles) would accommodate the most stations. However, spacings this close would require that ATV receivers be able to operate with much lower signal margins than existing NTSC receivers (6-10 dB vs. 28-45 dB). This condition may be very difficult for ATV technology to achieve. On the other hand, the 300-km (186 miles) spacing approximates the current NTSC cochannel minimum separations.

The tabulated nationwide percentages were found by a computerized exploration of assignment possibilities assuming no restrictions (e.g., UHF taboos) on augmentation channel assignments other than cochannel and adjacent channel constraints. While this assumption may be reasonable for new ATV receivers, some additional restrictions, such as the image taboo, may continue to be necessary to protect existing NTSC receivers. This would result in some reduction in the number of stations that could be accommodated.

In generating the tabulated values it was also assumed that the appropriate protection for Canadian and Mexican stations is the same as for those of the U.S. Present international working agreements provide significantly greater protection and, if such protection is maintained, would decrease the number of stations accommodated.

Table 1: LARGEST PERCENTAGE OF NEW ASSIGNMENTS FOUND POSSIBLE NATIONWIDE

The minimum separation distance for adjacent spectrum assignments is 96 km (60 miles) in all cases below.

AMOUNT OF ADDED SPECTRUM (MHz)	STATIONS ACCOMMODATED FOR MINIMUM SEPARATION AS INDICATED: 160 km (100 mi)	300 km (186 mi)	CONDITIONS
3 6	77% 63%	22% 17%	Added spectrum is contiguous with the current assignment of each station.
3 6	94% 84%	50% 38%	VHF stations augmented in VHF; UHF in UHF; contiguous assignments wherever possible.
3 6	100% 96%	77% 60%	VHF stations may be augmented in UHF and vice-versa; no preference for contiguity.

Of particular importance is the fact that many of the stations not accommodated in the Table 1 analyses would be in major cities. The tabulated percentages are the result of attempts to make the greatest number of assignments nationwide without special regard for stations serving major cities. We have not explored conditions under which all stations of major cities can be accommodated, or the extent to which both nationwide and major city requirements can be met simultaneously. However, if assignment criteria are uniformly applied in all areas, the results for major cities may be significantly less than for the whole country, as indicated by the sample results below:

Table 2
SAMPLE RESULTS IN 10 MAJOR CITIES
WHEN LARGE NUMBER OF ASSIGNMENTS IS SOUGHT FOR NATION AS A WHOLE

Conditions: Assignment criteria applied uniformly in all parts of the country; VHF stations augmented with VHF spectrum and UHF with UHF; contiguous assignments wherever possible; adjacent channel separation of 96 km (60 miles). Column headings show cochannel separation and augmentation channel bandwidth.

AREAS OF INTEREST	PRESENT NO. OF STATIONS	PERCENT OF STATIONS ACCOMMODATED 6 MHz 160 km	6 MHz 300 km	3 MHz 160 km	3 MHz 300 km
Major cities	116	59%	28%	75%	35%
United States	1760	84%	38%	94%	50%

The study concludes that if 100% of existing TV stations are to be accommodated with added spectrum for ATV, the technology must allow operation at substantially reduced interference protection ratios; alternatively some reduction in service areas would have to be accepted. It is not clear that these are realistic conditions for growth of an ATV service.

Additional work now planned will take into account certain taboos (to protect current TV receivers) and will seek to improve results through a limited amount of repacking, that is, by minor adjustments of channel allotments. This effort will look for ways to increase the percentage of stations that can be given ATV augmentation spectrum with less severe short-spacing than associated with the results presented here.

INTRODUCTION

General

The availability of spectrum for advanced television services is a principal concern of a proceeding currently before the Commission. In July 1987, the Commission issued a Notice of Inquiry beginning an investigation of the issues arising from the potential introduction of advanced television (ATV). 1/ In particular, the Commission is concerned with the possible impact this new service would have on the existing television broadcast service and on the Commission's spectrum allocation and television channel allotment policies.

The study reported here explores the availability of additional spectrum for ATV in the frequency bands currently allocated for terrestrial TV broadcasting. 2/ The additional spectrum would come from UHF channels made available by eliminating certain restrictions now imposed by the so-called "UHF taboos" and by reducing the geographical separation now required between cochannel and adjacent channel assignments. This easing of assignment criteria requires technological improvements in television transmission systems and receivers. In particular, new ATV technology must provide substantially better interference rejection characteristics than the current NTSC system.

ATV Systems and Spectrum Options

A variety of ATV systems are under development. Examples are listed in Appendix A. In general, these systems fall into three broad categories: (1) those that can operate within a single 6-MHz channel, i.e., no additional spectrum is required; (2) those that require an additional 3-MHz channel; and (3) those requiring an additional 6 MHz.

Spectrum availability is a concern even for some systems designed to operate within 6 MHz. Although some of these are compatible with existing NTSC receivers and do not require additional spectrum, others are not compatible. Preservation of existing service during implementation of such systems would necessitate simulcasting in a separate channel from the main NTSC TV channel.

Certain of the ATV systems requiring additional spectrum of 3 or 6 MHz also require that the additional spectrum be adjacent, or contiguous, to the existing TV channel. A description of how channels may be expanded with contiguous spectrum is given in Appendix B. Some of the limitations associated with expanding existing TV channels with additional contiguous spectrum can also be seen in Appendix B. This study investigates the availability of spectrum for both contiguous and non-contiguous spectrum options.

1/ See Notice of Inquiry in MM Docket No. 87-268, 2 FCC Record 5125 (1987).

2/ The availability of spectrum in other bands (e.g. 2.5 and 12 GHz) is not addressed, and no attention is given to proposed ATV systems that would operate within the 6 MHz presently assigned since they do not pose a spectrum availability problem.

ORGANIZATION OF THE ANALYSIS

The availability of spectrum for ATV is explored for a range of possible minimum separation distances and a variety of conditions related to the frequency separation between current and new assignments. The special case of contiguous supplemental channels is examined as well as more general cases in which supplemental spectrum may be separated from current assignments. 3/ Future work will investigate the question of whether substantial improvements in spectrum availability could be obtained by adjustments in the present table of TV allotments.

Methodology

The investigations are made using a computer program. The program explores possibilities for additional assignments nationwide, taking into account constraints due to stations of Canada and Mexico and land mobile reservations. The program tries to find the largest number of stations that can be accommodated nationwide. No preferences are given to the coverage of large urban areas.

The method used in the study is necessarily heuristic rather than exact because the number of possible ways to make assignments is too large to be examined completely, even by computer. The difficulties are easily appreciated: Since we cannot construct and individually evaluate every possibility, we must select a particular station for the first assignment and proceed sequentially. However, assignments made early in this process may later preclude making assignments to other stations. To make a large number of assignments it is necessary to make a good (in the sense of ultimately successful) choice of the order in which stations are addressed.

The method orders stations according to the apparent difficulty of finding a supplemental channel for them, and assignments are then made where possible to the stations in this order. The supplemental channel chosen for successive stations is one which, looking ahead, seems minimally to affect subsequent choices. After all stations have been addressed in this way, the entire process is repeated using different reordering criteria and different look-ahead techniques. Finally the largest number of stations accommodated in these trials is accepted as an estimate of the largest possible number of stations. These methods and their application to television allocations are described by William Hale [1].

3/ Augmentation by spectrum in the same band and close in frequency to the current assignment may be desirable even if not absolutely required. Problems may otherwise arise from radio propagation differences between the two component channels, and practical TV receivers may not be able to reconstruct the desired high quality ATV display. Difficulties of this kind are expected to be greater when there is wider separation in frequency between the main channel and the augmentation spectrum. The effects of these considerations are partially explored in this study by comparing spectrum availability in the absence of frequency separation constraints with availability under the condition that augmentation spectrum must be from the same band as the existing assignment (i.e., VHF stations augmented in VHF and UHF stations in UHF).

The total number of assignments made in the computer runs are significant as indications of what can be achieved by certain broadly outlined assignment strategies but are less useful as specific assignment plans. Many important details, such as coverage of major cities and frequency separation between new and current assignments, would need to be considered in developing actual assignments plans.

Range of Assumed Distance Separations

TV allotments are determined in part by the ability of television receivers to reject undesired signals in favor of the desired signal (D/U ratio). For instance, all stations must be located in such a way that those operating on the same channel or adjacent channels are separated by certain minimum distances; otherwise receivers would not be able to reject the undesired cochannel and adjacent channel signals. In addition, certain combinations of UHF channels are assigned only at specified minimum distances from one another because UHF receivers are particularly susceptible to interference from these combinations in any particular area. The resulting allocation constraints are known as UHF taboos. 4/

This study presumes that advances in the technology for delivering ATV service may allow the minimum distance separations for ATV stations to be less than those currently required. The UHF taboos have been ignored. 5/ Only the separation distances required to reduce adjacent and cochannel interference were observed.

To reflect the possibility of closer cochannel spacings for ATV stations, spectrum availability is examined over a range of minimum required separation distances. The study finds an approximate upper bound on the percentage of stations that can be assigned additional spectrum under minimum separation criteria ranging from 300 km (186 miles) to 160 km (100

4/ The UHF taboos and associated minimum separation distances to the nearest kilometer (or mile) are (see FCC Rules [2]):

(1) Intermodulation, cross-modulation and half-IF (n + or - 2, 3, 4, and 5 channels): 31 km (20 miles);

(2) Local oscilator (n + or - 7 channels): 96 km (60 miles);

(3) IF beat (n + or - 8 channels): 31 km (20 miles);

(4) Sound image (n + or - 14 channels): 96 km (60 miles);

(5) Picture image (n + or - 15 channels): 120 km (75 miles).

5/ The characteristics of the existing population of TV receivers, however, cannot be ignored. Accordingly, OET undertook a separate study of the immunity of existing TV receivers to ATV signals (see reference [3]). This study concludes that through careful design of ATV transmissions, many of the current taboos may not need to be applied. Nevertheless, this matter will have to be examined more closely when actual ATV equipment becomes available for test.

miles). The distance of 300 km was chosen to represent the present NTSC cochannel minimum separation distance. 6/ Closer spacings were tried until, at 160 km, it became possible under certain conditions to accommodate 100% of stations. (To obtain this full accommodation at 160 km it is necessary to supplement some VHF stations with spectrum in the UHF band and vice-versa.)

Although separations as small as 160 km (100 miles) were investigated, substantial questions remain about whether it is realistic to consider making cochannel assignments this close. Such spacings would require that ATV receivers be able to operate with much lower signal margins than existing NTSC receivers. NTSC service extends to at least about 64 km (40 miles) without interference from cochannel stations with today's minimum spacing requirements. To provide the same coverage for ATV stations separated by only 160 km, receivers must be able to operate with a signal margin of only 6-10 dB in place of the 28-45 dB margin typical of NTSC receivers. This condition may be very difficult for ATV technology to achieve, and shortcomings in this respect would result in reduced service areas.

If stations are allowed to be geographically closer to one another than they are at present, the new ATV broadcasting technology must provide improvements in the interference rejection capability of TV receivers. Receiver characteristics in this respect are determined by tests in which the desired-to-undesired (D/U) signal ratio at the input of the receiver is correlated with TV picture quality as rated by observers. The tests are made under laboratory conditions in which the desired and undesired signal inputs can be varied to study the full range of conditions that might be presented to an actual receiver. Tests on NTSC receivers have been conducted in this way on a number of occasions in the past. In 1949, JTAC 7/ provided data in this form to assist the FCC in early decisions concerning TV broadcast allocations [4]. In a comprehensive study of engineering factors underlying the allocation of frequencies for TV, TASO 8/ conducted further tests of this kind in the late 1950s [5], and a systematic presentation of these TASO results appears in an FCC technical report of 1960 [6]. Similar tests were made by the FCC in 1983 [7] and again in 1987 [8]. (The 1983 FCC tests were made in connection with a prototype advanced technology receiver, and those of 1987 were concerned with NTSC receivers in relation to the UHF taboos.) Data in this or equivalent form for competing ATV prototypes is needed to support decisions on spectrum allocation.

6/ The distance of 300 km (186 miles) is an approximation of the current minimum required separation. In fact, the minimum separation requirements range between 248.6 km (154.5 miles) and 353.2 km (219.5 miles) depending on geographical area and frequency band. See Section 73.610 of FCC Rules [2].

7/ The Joint Technical Advisory Committee (JTAC) consisted of representatives of the Institute of Radio Engineers (IRE, a predecessor of the IEEE) and the Radio Manufacturers' Association (RMA, predecessor to the EIA).

8/ The Television Allocations Study Organization (TASO) was established by the television industry in 1956 responding to an FCC request.

In application to allocation decisions, the D/U ratio required by receivers is compared to the predicted ratio between received signals. A channel assignment of interest is permissible if the predicted D/U ratio is at least as great as the one required by receivers. The predicted ratio depends on the distance separating the two stations; the required ratio is that determined by receiver tests like those performed by JTAC, TASO and the FCC on the occasions mentioned. Tables relating separation distances to predicted D/U ratios are presented in Appendix C. The predictions are made from propagation curves contained in the FCC rules [2]. The ratios tabulated are median values; actual values vary in ways that can be described statistically.

Data Base

The data base used for the analysis consisted of 1760 TV stations from the Commission's records as of June 1988. Of these, 706 were VHF and 1054 were UHF. The data base includes (1) licensed stations, (2) prospective stations with valid construction permits and (3) pending applications that have been accepted for filing. Protection also was provided for existing land mobile operations on channels 14 through 20 in eleven major urban areas. 9/ Existing Canadian and Mexican TV allotments were treated as requiring the same protection as U.S. allotments but not requiring additional spectrum for ATV purposes. Low power television (LPTV) and translator stations were not included in this data base due to their secondary status. Therefore, it is possible that some authorized LPTV stations may conflict with certain potential ATV assignments.

RESULTS

Contiguous Spectrum

The first set of analyses addresses ATV systems that require augmentation with contiguous spectrum of either 3 or 6 MHz. Table 3 presents the results of these analyses for minimum separation distances between 300 km (186 miles) and 160 km (100 miles) in 10 km intervals (approximately every 6 miles). The required (minimum) separation between adjacent channel assignments is 96 km (60 miles).

The numbers tabulated are approximate upper bounds on how many stations could be assigned supplemental spectrum. In each case a list of assignments satisfying the separation distance constraints was actually generated by the procedure described above which tends to maximize the number of assignments. Since these assignments do in fact satisfy the constraints, at least this many can be made; since the procedure is heuristic rather than mathematically ideal, it is possible that some additional stations could be accommodated.

9/ Channels for thirteen areas are listed in Section 90.303 of the Commission's Rules [2]. However, the channels listed for Cleveland and Detroit are not in use because the concurrence of Canada has not been obtained.

Table 3 shows that 77% of all stations could be provided with 3 MHz of contiguous spectrum (63% if 6 MHz is provided) if the minimum cochannel separation is reduced to 160 km. If, on the other hand, current cochannel separation requirements are retained, only 22% of all stations could be accommodated with 3 MHz of spectrum (17% if 6 MHz is provided).

Table 3
NUMBER OF STATIONS WHERE CONTIGUOUS SPECTRUM CAN BE ASSIGNED

MINIMUM SEPARATION DISTANCE		NUMBER OF STATIONS FOR WHICH CONTIGUOUS SUPPLEMENTAL SPECTRUM IS AVAILABLE					
		6-MHz Supplement			3-MHz Supplement		
km	miles	VHF	UHF	Total	VHF	UHF	Total
300	186	24	271	295 (17%)	37	358	395 (22%)
290	180	29	294	323 (18%)	43	387	430 (24%)
280	174	38	317	355 (20%)	53	413	466 (26%)
270	168	50	359	409 (23%)	68	467	535 (30%)
260	162	62	389	451 (26%)	82	506	588 (33%)
250	155	75	420	495 (28%)	98	545	643 (37%)
240	149	83	439	522 (30%)	106	565	671 (38%)
230	143	94	473	567 (32%)	122	600	722 (41%)
220	137	114	523	637 (36%)	144	651	795 (45%)
210	131	150	558	708 (40%)	192	692	884 (50%)
200	124	192	602	794 (45%)	244	738	982 (56%)
190	118	233	651	884 (50%)	294	785	1079 (61%)
180	112	263	690	953 (54%)	346	823	1169 (66%)
170	106	295	722	1017 (58%)	392	855	1247 (71%)
160	100	336	773	1109 (63%)	448	900	1348 (77%)

Supplementary Channels, Not Necessarily Contiguous

The second set of analyses addresses cases in which the additional spectrum does not have to be contiguous. Tables 4 through 6 present the results of these analyses for the same range of cochannel separations as was used in developing results for the previous case (Table 3) where contiguous spectrum is required. The required separation between adjacent channel assignments is 96 km (60 miles), also the same as before. The tables in the series beginning with Table 3 are therefore parallel with respect to separation distances; the tables differ with respect to the constraints imposed on choice of frequency.

Tables 4 through 6 describe progressively more restrictive conditions on choice of frequency. The more restrictive conditions result in fewer stations being accommodated, but the progression is also in the direction of conditions that may be more easily satisfied in practice.

- Table 4 shows the results when the only limitations on frequency assignments are that they be within the band presently allocated for terrestrial TV broadcasting and do not violate cochannel or adjacent channel distance constraints. It is found that 100% of all stations can be provided with 3 MHz of supplemental spectrum (96% if 6 MHz is provided) if the minimum cochannel separation distance for the ATV stations is reduced to 160 km. If, on the other hand, current cochannel separation requirements are retained, only about 77% of all stations could be accommodated with 3 MHz of supplemental spectrum (60% if 6 MHz is provided).

- Table 5 shows the results when a preference is given to making as many contiguous assignments as possible. In terms of percentage accommodation, only a slight loss is caused by this special condition on choice of frequency. We see that almost 100% of all stations could still be provided with 3 MHz of supplemental spectrum (95% if 6 MHz is provided) if the cochannel separation requirement is reduced to 160 km. If current separation requirements are retained, only 76% of all stations can be accommodated with 3 MHz of supplemental spectrum (59% if 6 MHz is provided).

- Table 6 shows the consequences of requiring that supplemental frequency assignments for VHF stations be in the VHF band and supplemental assignments for UHF stations be chosen in the UHF band. Preference is still given to contiguous assignments. Here we observe that 94% of all stations can be provided with supplemental spectrum (84% if 6 MHz is provided) if cochannel separations as close as 160 km are allowed. Under current minimum separation requirements, however, only 50% of all stations can be accommodated (38% if 6 MHz is provided).

Table 7 is included to emphasize the fact that results for major cities should not be expected to look like those for the nation as a whole. We have not explored conditions under which all stations of major cities can be accommodated, or the extent to which both nationwide and major city requirements can be met simultaneously. However, if assignment criteria are uniformly applied in all areas, the results for major cities may be significantly less than for the whole country, as indicated by the sample results presented in Table 7. The table shows the fallout in selected major cities of computer runs that gave no special preferences to them. The computer runs involved are those corresponding to Table 6, in which VHF stations are augmented in VHF and UHF stations in UHF.

Table 4
NUMBER OF STATIONS WHERE UHF OR VHF SPECTRUM CAN BE ASSIGNED

Conditions: VHF stations may be augmented in UHF and vice-versa; no preference for contiguous spectrum.

MINIMUM SEPARATION DISTANCE		NUMBER OF STATIONS ASSIGNED SUPPLEMENTAL SPECTRUM					
		6-MHz Supplement			3-MHz Supplement		
km	miles	VHF	UHF	Total	VHF	UHF	Total
300	186	536	522	1058 (60%)	605	751	1356 (77%)
290	180	553	556	1109 (63%)	626	773	1399 (79%)
280	174	560	593	1153 (66%)	642	810	1452 (83%)
270	168	578	650	1228 (70%)	648	851	1499 (85%)
260	162	597	677	1274 (72%)	656	888	1544 (88%)
250	155	604	718	1322 (75%)	662	920	1582 (90%)
240	149	614	752	1366 (78%)	675	936	1611 (92%)
230	143	627	784	1411 (80%)	676	964	1640 (93%)
220	137	640	842	1482 (84%)	677	985	1662 (94%)
210	131	655	873	1528 (87%)	686	1007	1693 (96%)
200	124	658	917	1575 (89%)	698	1022	1720 (98%)
190	118	666	944	1610 (91%)	702	1030	1732 (98%)
180	112	677	965	1642 (93%)	705	1042	1747 (99.3%)
170	106	678	979	1657 (94%)	706	1048	1754 (99.7%)
160	100	691	992	1683 (96%)	706	1054	1760 (100%)

Table 5
NUMBER OF STATIONS WHERE UHF OR VHF SPECTRUM CAN BE ASSIGNED

Conditions: VHF stations may be augmented in UHF and vice-versa; as many contiguous channels as possible are assigned before proceeding to make other assignments.

MINIMUM SEPARATION DISTANCE		NUMBER OF STATIONS ASSIGNED SUPPLEMENTAL SPECTRUM					
		6-MHz Supplement			3-MHz Supplement		
km	miles	VHF	UHF	Total	VHF	UHF	Total
300	186	505	536	1041 (59%)	581	756	1337 (76%)
290	180	522	569	1091 (62%)	606	785	1391 (79%)
280	174	533	610	1143 (65%)	613	815	1428 (81%)
270	168	555	652	1207 (69%)	623	857	1480 (84%)
260	162	561	694	1255 (71%)	635	884	1519 (86%)
250	155	571	728	1299 (74%)	647	915	1562 (89%)
240	149	587	753	1340 (76%)	660	945	1605 (91%)
230	143	598	798	1396 (79%)	663	962	1625 (92%)
220	137	613	853	1466 (83%)	671	985	1656 (94%)
210	131	625	888	1513 (86%)	677	1003	1680 (95%)
200	124	639	925	1564 (89%)	689	1019	1708 (97%)
190	118	645	952	1597 (91%)	696	1026	1722 (98%)
180	112	660	969	1629 (93%)	702	1044	1746 (99.2%)
170	106	661	987	1648 (94%)	702	1049	1751 (99.5%)
160	100	675	1002	1677 (95%)	706	1053	1759 (99.9%)

Table 6
NUMBER OF STATIONS WHERE SAME-BAND SPECTRUM CAN BE ASSIGNED

Conditions: VHF stations augmented within VHF, and UHF within UHF; preference given to contiguous spectrum.

MINIMUM SEPARATION DISTANCE		NUMBER OF STATIONS ASSIGNED SUPPLEMENTAL SPECTRUM					
		6-MHz Supplement			3-MHz Supplement		
km	miles	VHF	UHF	Total	VHF	UHF	Total
300	186	47	626	673 (38%)	70	811	881 (50%)
290	180	60	656	716 (41%)	87	849	936 (53%)
280	174	72	698	770 (44%)	106	873	979 (56%)
270	168	88	733	821 (47%)	125	906	1031 (59%)
260	162	111	764	875 (50%)	150	929	1079 (61%)
250	155	131	799	930 (53%)	183	956	1139 (65%)
240	149	146	819	965 (55%)	211	985	1196 (68%)
230	143	171	864	1035 (59%)	247	997	1244 (71%)
220	137	201	899	1100 (63%)	282	1017	1299 (74%)
210	131	254	925	1179 (67%)	356	1029	1385 (79%)
200	124	297	962	1259 (72%)	416	1044	1460 (83%)
190	118	343	976	1319 (75%)	474	1045	1519 (86%)
180	112	377	995	1372 (78%)	516	1053	1569 (89%)
170	106	405	1004	1409 (80%)	559	1054	1613 (92%)
160	100	453	1027	1480 (84%)	601	1054	1655 (94%)

Table 7
SAMPLE RESULTS IN MAJOR CITIES
WHEN A LARGE NUMBER OF ASSIGNMENTS IS SOUGHT FOR NATION AS A WHOLE

Conditions: VHF stations augmented with VHF spectrum and UHF with UHF; contiguous assignments wherever possible; adjacent channel separation of 96 km (60 miles).

The number of stations accommodated in particular cities does not always vary consistently with number accommodated nationwide. This reflects the fact that the computer runs were targeted on the nation as a whole.

CITY	NUMBER OF STATIONS	NUMBER OF STATIONS PROVIDED 6-MHZ SUPPLEMENTAL SPECTRUM AT INDICATED COCHANNEL SEPARATION			
		160 km (100 mi)	200 km (124 mi)	250 km (155 mi)	300 km (186 mi)
New York	12	5	0	1	0
Los Angeles	15	9	5	4	5
Chicago	13	9	8	5	2
Philadelphia	10	5	2	1	0
San Francisco	13	8	7	6	8
Boston	10	4	2	2	0
Detroit	7	3	0	0	0
Dallas/Ft. Worth	15	11	10	10	9
Washington DC	10	6	5	1	0
Houston	11	9	9	9	8
Nationwide	1760	1480/84%	1259/72%	930/53%	673/38%

CITY	NUMBER OF STATIONS	NUMBER OF STATIONS PROVIDED 3-MHZ SUPPLEMENTAL SPECTRUM AT INDICATED COCHANNEL SEPARATION			
		160 km (100 mi)	200 km (124 mi)	250 km (155 mi)	300 km (186 mi)
New York	12	6	4	2	1
Los Angeles	15	12	10	8	5
Chicago	13	10	9	8	2
Philadelphia	10	6	4	0	1
San Francisco	13	9	8	8	8
Boston	10	7	6	4	3
Detroit	7	4	3	1	1
Dallas/Ft. Worth	15	14	11	10	9
Washington DC	10	8	6	3	3
Houston	11	11	10	9	8
Nationwide	1760	1655/94%	1460/83%	1139/65%	881/50%

CONCLUSIONS

ATV systems must be able to operate at reduced minimum separation distances. If the minimum separation distances of the current FCC rules are retained, it is impossible to accommodate all TV stations.

ATV systems must have substantially better interference rejection characteristics than existing NTSC systems. Shortcomings in interference rejection capability would result in reductions in service areas, and such reductions would have the greatest impact on broadcast TV service in the major cities. (ATV systems must also be designed to avoid interfering with service provided by existing NTSC stations.)

ATV systems that require a continuous span of 9 or 12 MHz cannot be accommodated without a restructuring of the present broadcasting system and allotment table. Contiguous spectrum, i.e. spectrum adjacent to current assignments, is available to no more than about 80% of existing TV stations under any conditions that seem realistic.

Further work is needed to investigate possibilities for accommodation of all stations with more favorable spacing by some degree of repacking, that is, by minor adjustments of channel allotments.

REFERENCES

[1] William K. Hale, "New Spectrum Management Tools," Proceedings of the 1981 IEEE International Symposium on Electromagnetic Compatibility, Boulder CO, August 18-20, 1981.

[2] Code of Federal Regulations, Title 47, Chapter I, "Federal Communications Commission", Parts 70-79, U. S. Government Printing Office, Washington DC, 1987. Distance separation requirements for the UHF taboos are tabulated in Section 73.698. Radiowave propagation prediction curves are presented as Figures 9-10 in Section 73.699.

[3] H. Davis, Analysis of UHF TV Receiver Interference Immunities Relative to Advanced Television, OET Technical Memorandum No. FCC/OET TM88-2, August 1988.

[4] Comments on the Proposed Allocation of Television Broadcast Services, Report of the Joint Technical Advisory Committee (IRE-RMA) to the Federal Communications Commission, September 26, 1949. Published as Proceedings of the JTAC, Volume IV.

[5] Engineering Aspects of Television Allocations, Report of the Television Allocations Study Organization to the Federal Communications Commission, March 16, 1959. Copies may be available from Wallace-Homestead Books, 1912 Grand Avenue, Des Moines, IA 50309 (Tel. 515-243-6181).

[6] Harry Fine, A Further Analysis of TASO Panel 6 Data on Signal to Interference Ratios and their Application to Description of Television Service, FCC/OCE Report No. 5.1.2, April 1960.

[7] H. Davis, Advanced Technology Receiver Study, Part 1, Receiver Performance Measurements, FCC Report No. FCC/OST R-83-1, February 1983.

[8] A Study of UHF Television Receiver Interference Immunities, FCC Technical Memorandum FCC/OET TM87-3, 1987

APPENDIX A

EXAMPLES OF THE ATV SYSTEMS UNDER DEVELOPMENT

Some ATV systems can operate within a single 6-MHz channel. Such systems would not require extra spectrum except for the purpose of simultaneously broadcasting an NTSC and an ATV signal. The list below is from R. K. Jurgen, "High-definition Television Update", <u>IEEE Spectrum</u>, April 1988.

SINGLE-CHANNEL SYSTEMS	INDUSTRIAL DEVELOPER	SPECTRUM REQUIREMENT (MHz)
ACTV	NBC, RCA, Sarnoff	6
Bandwidth-efficient	MIT	6
Fukinuki	Hitachi	6
HD-NTSC	Del Rey Group	6
Receiver-compatible	MIT	6
SuperNTSC	Faroudja Labs	6
Yasumoto	Matsushita	6

Systems requiring more than 6 MHz for transmission are:

WIDE-BANDWIDTH SYSTEMS	INDUSTRIAL DEVELOPER	SPECTRUM REQUIREMENT (MHz)
HDMAC-60	North American Philips	9.5
MUSE	NHK, Japan	10
HDV-MAC	Scientific Atlanta	10.7

The systems above need <u>contiguous</u> spectrum in contrast to certain others. Others (below) could be implemented with separate augmentation channels selected in a way to minimize potential interference.

DUAL-CHANNEL SYSTEMS	INDUSTRIAL DEVELOPER	SPECTRUM REQUIREMENT (MHz)
Glenn	N.Y. Institute of Technology	6 + 3
AT&T	Bell Laboratories	6 + 6
HDNTSC	North American Philips	6 + 6

APPENDIX B

HOW CHANNELS MAY BE EXPANDED WITH CONTIGUOUS SPECTRUM

Contiguous spectrum is required for a number of the ATV systems under development, including HDMAC-60 (North American Philips), MUSE (NHK, Japan), HDV-MAC (Scientific Atlanta).

Suitable plans for channelization with contiguous spectrum involve some complexities because of gaps in the TV broadcast spectrum. For example, channel 4 can be augmented by contiguous spectrum overlapping channel 3 (the lower adjacent channel), but channel 5 must be augmented by contiguous spectrum overlapping channel 6 (upper adjacent).

```
xx|__|__|__|xx|__|__|xx|__|__|__|__|__|__|__|xx
   02 03 04    05 06    07 08 09 10 11 12 13

xx|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|xx
   14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36

xx|__|__|__|__|__|__|__|__|__|__|__|__|__|.. and so on to ..|__|xx
   38 39 40 41 42 43 44 45 46 47 48 49 50                     69
```

Four approaches to annexing contiguous spectrum to existing channels can be distinguished, as illustrated below. The last approach, labeled "Upper or lower", allows by far the largest number of wideband channels.

UPPER: Adding upper adjacent spectrum is not possible for about 215 existing stations nationwide.

```
          |________________|_______...
              Channel N       N+1
```

LOWER: Adding lower adjacent spectrum is not possible for about 225 stations.

```
...______|________________|
    N-1       Channel N
```

UPPER AND LOWER: Using both upper and lower has disadvantages of both.

```
  ...____|________________|____...
    N-1       Channel N      N+1
```

UPPER OR LOWER: Assuming a system in which either can be used obtains the advantages of both.

```
..........|________________|..........
    N-1        Channel N       N+1
```

APPENDIX C

TABLES RELATING SEPARATION DISTANCES TO D/U RATIOS

In order to share the same channel, two stations should be separated by a distance sufficient to make the other signal relatively small everywhere within either's service area. Tables in this appendix relate separation distance to the ratio between respective signals expected at specific reception distances from the desired station. The shorter the reception distance, the larger the predicted desired-to-undesired (D/U) ratio; greater separation distances also provide greater D/U ratios.

Tables C-1 through C-3 are for low VHF (channels 2-6), high VHF (channels 7-13), and UHF (channels 14-69) respectively.

The values tabulated are medians with respect to variations from place to place. The standard deviation of these variations may be estimated as 11 dB for low band VHF (channels 2-6; 54-88 MHz), and the standard deviation is greater by about 2 dB for every doubling of frequency. These estimates are made assuming that variations in desired and undesired signals are independent. The value for low band and the estimate of frequency dependence comes from a report by John Egli entitled "Radio Propagation above 40 MC over Irregular Terrain", Proc. IRE, Vol. 45, No. 10, October 1957.

SEPARATION DIST (km)	D/U (in dB) AT INDICATED CONTOUR DISTANCE (contour distances in kilometers) 32.0	40.0	48.0	56.0	64.0	72.0	80.0	88.0	96.0	104.0
300.0	56.1	50.4	44.9	39.8	34.9	30.1	25.3	20.6	15.8	11.3
290.0	54.5	48.7	43.2	38.1	33.2	28.4	23.6	18.9	14.1	9.5
280.0	52.8	47.0	41.6	36.5	31.5	26.7	21.9	17.1	12.2	7.6
270.0	51.1	45.3	39.9	34.8	29.8	25.0	20.1	15.2	10.4	5.9
260.0	49.5	43.7	38.2	33.1	28.1	23.2	18.2	13.4	8.7	4.1
250.0	47.8	42.0	36.5	31.3	26.2	21.3	16.5	11.7	6.9	2.2
240.0	46.1	40.3	34.7	29.5	24.4	19.6	14.7	9.9	5.0	0.1
230.0	44.4	38.5	32.9	27.6	22.6	17.8	12.9	7.9	2.9	-2.0
220.0	42.6	36.6	31.1	25.9	20.9	15.9	10.9	5.8	0.7	-4.2
210.0	40.7	34.8	29.3	24.1	19.0	13.9	8.8	3.7	-1.5	-6.9
200.0	38.9	33.1	27.5	22.2	16.9	11.8	6.6	1.3	-4.3	-10.0
190.0	37.2	31.3	25.6	20.1	14.8	9.6	4.2	-1.6	-7.5	-13.1
180.0	35.3	29.3	23.4	18.0	12.6	7.1	1.2	-4.7	-10.6	-16.4
170.0	33.3	27.1	21.3	15.7	9.9	4.0	-2.0	-7.9	-14.0	-19.9
160.0	31.1	25.0	19.0	12.9	6.8	0.8	-5.2	-11.3	-17.5	-23.7

SEPARATION DIST (mi)	D/U (in dB) AT INDICATED CONTOUR DISTANCE (contour distances in miles) 20.0	25.0	30.0	35.0	40.0	45.0	50.0	55.0	60.0	65.0
190.0	56.9	51.1	45.7	40.6	35.6	30.8	26.0	21.2	16.5	12.0
185.0	55.6	49.8	44.3	39.2	34.3	29.4	24.7	19.9	15.1	10.6
180.0	54.3	48.5	43.0	37.9	32.9	28.1	23.3	18.5	13.7	9.1
175.0	52.9	47.1	41.7	36.5	31.5	26.7	21.9	17.1	12.2	7.6
170.0	51.6	45.8	40.3	35.2	30.2	25.4	20.5	15.6	10.7	6.2
165.0	50.3	44.4	39.0	33.8	28.8	23.9	19.0	14.1	9.3	4.8
160.0	48.9	43.1	37.6	32.4	27.4	22.4	17.5	12.7	7.9	3.3
155.0	47.5	41.7	36.2	31.0	25.9	20.9	16.1	11.3	6.4	1.8
150.0	46.2	40.3	34.8	29.5	24.4	19.5	14.7	9.8	4.9	0.1
145.0	44.8	38.9	33.3	28.0	23.0	18.1	13.2	8.3	3.2	-1.6
140.0	43.4	37.4	31.8	26.6	21.6	16.7	11.7	6.6	1.5	-3.4
135.0	41.9	35.9	30.4	25.2	20.1	15.1	10.0	4.9	-0.2	-5.2
130.0	40.4	34.5	29.0	23.8	18.6	13.5	8.3	3.2	-2.1	-7.5
125.0	39.0	33.1	27.5	22.2	16.9	11.7	6.6	1.3	-4.4	-10.0
120.0	37.6	31.7	26.0	20.6	15.2	10.0	4.7	-1.0	-6.9	-12.6
115.0	36.1	30.1	24.3	18.8	13.5	8.1	2.4	-3.5	-9.4	-15.1
110.0	34.6	28.5	22.6	17.1	11.6	5.9	-0.1	-6.0	-12.0	-17.9
105.0	32.9	26.7	20.9	15.2	9.3	3.3	-2.6	-8.6	-14.7	-20.7
100.0	31.2	25.0	19.0	12.9	6.8	0.8	-5.2	-11.4	-17.6	-23.8

Conditions: Both transmitters have the same power, and both transmitting antennas are at a height of 305 meters (1000 feet) above average terrain. The D/U ratios appearing in the table are determined from propagation prediction curves in FCC rules. At the indicated contour distance, a signal ratio at least this great is expected at 50% of locations at least 90% of the time.

TABLE C-1. D/U Ratios for Low VHF Stations (Channels 2-6)

SEPARATION DIST (km)	D/U (in dB) AT INDICATED CONTOUR DISTANCE (contour distances in kilometers) 32.0	40.0	48.0	56.0	64.0	72.0	80.0	88.0	96.0	104.0
300.0	59.3	53.9	48.4	42.9	37.5	32.0	26.7	21.6	16.6	11.6
290.0	57.7	52.2	46.7	41.2	35.7	30.3	25.1	19.8	14.7	9.9
280.0	56.0	50.4	44.9	39.4	34.0	28.7	23.2	18.0	13.0	8.1
270.0	54.2	48.7	43.2	37.8	32.3	26.8	21.4	16.2	11.2	6.3
260.0	52.5	47.0	41.5	36.0	30.4	25.0	19.7	14.4	9.4	4.5
250.0	50.8	45.3	39.7	34.1	28.7	23.2	17.9	12.6	7.6	2.6
240.0	49.1	43.4	37.9	32.4	26.9	21.5	16.1	10.8	5.7	0.6
230.0	47.2	41.6	36.1	30.6	25.1	19.6	14.2	8.9	3.7	-1.5
220.0	45.4	39.9	34.3	28.8	23.3	17.8	12.3	6.8	1.5	-4.0
210.0	43.7	38.1	32.5	27.0	21.4	15.8	10.2	4.6	-1.1	-6.9
200.0	41.9	36.3	30.7	25.1	19.4	13.7	7.9	2.0	-4.1	-10.2
190.0	40.1	34.4	28.8	23.1	17.3	11.3	5.1	-1.2	-7.4	-13.5
180.0	38.2	32.5	26.7	20.9	14.8	8.5	2.0	-4.5	-10.8	-17.5
170.0	36.3	30.4	24.5	18.3	11.9	5.2	-1.3	-8.0	-14.9	-21.9
160.0	34.1	28.1	21.9	15.3	8.6	1.9	-5.0	-12.2	-19.3	-26.0

SEPARATION DIST (mi)	D/U (in dB) AT INDICATED CONTOUR DISTANCE (contour distances in miles) 20.0	25.0	30.0	35.0	40.0	45.0	50.0	55.0	60.0	65.0
190.0	60.1	54.7	49.2	43.7	38.2	32.8	27.4	22.3	17.3	12.4
185.0	58.8	53.3	47.8	42.3	36.8	31.4	26.0	20.9	15.8	10.9
180.0	57.5	51.9	46.4	40.9	35.4	30.0	24.7	19.4	14.3	9.5
175.0	56.1	50.5	45.0	39.5	34.0	28.7	23.2	17.9	12.9	8.1
170.0	54.7	49.1	43.6	38.1	32.7	27.2	21.7	16.5	11.5	6.6
165.0	53.3	47.7	42.3	36.8	31.2	25.7	20.3	15.1	10.1	5.2
160.0	51.9	46.4	40.9	35.3	29.7	24.3	18.9	13.7	8.6	3.7
155.0	50.5	45.0	39.4	33.8	28.3	22.9	17.5	12.2	7.1	2.2
150.0	49.2	43.5	37.9	32.4	26.9	21.4	16.0	10.7	5.6	0.6
145.0	47.7	42.0	36.5	31.0	25.5	20.0	14.5	9.2	4.0	-1.1
140.0	46.2	40.6	35.1	29.6	24.0	18.5	13.0	7.6	2.3	-3.0
135.0	44.8	39.2	33.7	28.1	22.5	17.0	11.4	5.9	0.4	-5.1
130.0	43.4	37.8	32.2	26.6	21.0	15.4	9.7	4.1	-1.7	-7.6
125.0	42.0	36.3	30.7	25.1	19.4	13.7	7.8	1.9	-4.2	-10.2
120.0	40.5	34.8	29.2	23.5	17.7	11.8	5.7	-0.6	-6.8	-12.9
115.0	39.0	33.3	27.6	21.8	15.8	9.7	3.2	-3.2	-9.5	-15.8
110.0	37.5	31.7	25.9	19.9	13.7	7.2	0.6	-5.9	-12.4	-19.3
105.0	35.9	30.0	24.0	17.8	11.2	4.6	-2.1	-8.8	-15.9	-22.8
100.0	34.2	28.2	21.9	15.3	8.6	1.9	-5.0	-12.2	-19.4	-26.1

Conditions: Both transmitters have the same power, and both transmitting antennas are at a height of 305 meters (1000 feet) above average terrain. The D/U ratios appearing in the table are determined from propagation prediction curves in FCC rules. At the indicated contour distance, a signal ratio at least this great is expected at 50% of locations at least 90% of the time.

TABLE C-2. D/U Ratios for High VHF Stations (Channels 7-13)

SEPARATION DIST (km)	D/U (in dB) AT INDICATED CONTOUR DISTANCE (contour distances in kilometers) 32.0	40.0	48.0	56.0	64.0	72.0	80.0	88.0	96.0	104.0
300.0	58.3	51.8	45.2	38.7	32.3	26.4	21.1	16.0	11.3	6.9
290.0	56.7	50.1	43.6	37.1	30.6	24.7	19.3	14.3	9.6	5.2
280.0	55.1	48.5	41.9	35.4	28.9	23.0	17.6	12.6	7.9	3.5
270.0	53.5	46.8	40.2	33.7	27.2	21.2	15.9	10.9	6.2	1.6
260.0	51.8	45.1	38.5	31.9	25.5	19.5	14.2	9.1	4.2	-0.3
250.0	50.1	43.4	36.8	30.2	23.8	17.9	12.4	7.2	2.5	-2.0
240.0	48.4	41.7	35.0	28.5	22.1	16.0	10.5	5.4	0.7	-3.9
230.0	46.6	39.9	33.4	26.8	20.1	14.1	8.7	3.6	-1.2	-5.8
220.0	44.9	38.3	31.6	24.9	18.3	12.4	6.9	1.7	-3.2	-7.9
210.0	43.2	36.4	29.7	23.1	16.6	10.5	5.0	-0.3	-5.3	-10.2
200.0	41.4	34.5	27.9	21.3	14.7	8.6	3.0	-2.4	-7.7	-12.8
190.0	39.5	32.8	26.1	19.4	12.7	6.6	0.8	-4.9	-10.3	-15.6
180.0	37.7	31.0	24.2	17.4	10.7	4.3	-1.7	-7.5	-13.1	-18.7
170.0	35.9	29.0	22.2	15.3	8.3	1.7	-4.4	-10.4	-16.3	-22.5
160.0	34.0	27.0	20.1	12.9	5.8	-1.0	-7.3	-13.7	-20.3	-27.1

SEPARATION DIST (mi)	D/U (in dB) AT INDICATED CONTOUR DISTANCE (contour distances in miles) 20.0	25.0	30.0	35.0	40.0	45.0	50.0	55.0	60.0	65.0
190.0	59.1	52.5	45.9	39.4	33.0	27.1	21.8	16.7	12.0	7.5
185.0	57.8	51.2	44.6	38.1	31.7	25.7	20.4	15.3	10.6	6.1
180.0	56.5	49.9	43.3	36.8	30.3	24.4	19.0	13.9	9.2	4.8
175.0	55.2	48.6	42.0	35.4	28.9	23.0	17.6	12.5	7.8	3.4
170.0	53.9	47.2	40.6	34.0	27.5	21.6	16.2	11.2	6.5	1.9
165.0	52.6	45.9	39.2	32.6	26.1	20.2	14.8	9.8	5.0	0.4
160.0	51.2	44.5	37.9	31.2	24.7	18.8	13.5	8.3	3.4	-1.0
155.0	49.8	43.1	36.5	29.8	23.4	17.5	12.0	6.8	2.0	-2.5
150.0	48.4	41.7	35.1	28.5	22.0	15.9	10.4	5.3	0.6	-4.0
145.0	47.0	40.3	33.7	27.1	20.5	14.4	9.0	3.9	-0.9	-5.5
140.0	45.7	39.0	32.4	25.6	19.0	13.0	7.6	2.4	-2.5	-7.1
135.0	44.3	37.6	30.8	24.1	17.6	11.6	6.1	0.9	-4.1	-8.9
130.0	42.9	36.1	29.3	22.7	16.1	10.1	4.5	-0.7	-5.8	-10.8
125.0	41.4	34.6	27.9	21.2	14.6	8.5	2.9	-2.5	-7.8	-12.9
120.0	39.9	33.1	26.5	19.7	13.1	6.9	1.2	-4.4	-9.8	-15.1
115.0	38.5	31.7	25.0	18.2	11.5	5.2	-0.8	-6.5	-12.0	-17.4
110.0	37.1	30.2	23.4	16.6	9.7	3.2	-2.8	-8.7	-14.4	-20.2
105.0	35.5	28.6	21.8	14.8	7.8	1.1	-5.0	-11.0	-17.1	-23.5
100.0	34.0	27.0	20.1	12.9	5.7	-1.1	-7.4	-13.8	-20.4	-27.2

Conditions: Both transmitters have the same power, and both transmitting antennas are at a height of 366 meters (1200 feet) above average terrain. The D/U ratios appearing in the table are determined from propagation prediction curves in FCC rules. At the indicated contour distance, a signal ratio at least this great is expected at 50% of locations at least 90% of the time.

TABLE C-3. D/U Ratios for UHF Stations (Channels 14-69)